Light Exposure Dependence of the Staebler-Wronski Effect in nc-Ge/a-Si:H Thin Films

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UROP – Summer 2013

Introduction

Staebler-Wronski effect (SWE): Reversible light-induced degradation of the photo- and dark conductivity in hydrogenated amorphous silicon thin films (a-Si:H).

We investigated the SWE & its dependence on the number of incident photons in mixed-phase a-Si:H thin films embedded with germanium nanocrystals (nc-Ge/a-Si:H).

Theory

The SWE is caused by the reversible structural defects in a-Si:H created by photons as the material is exposed to light.

Defects lead to the reductions in the material's dark conductivity & photoconductivity.

Defects can be eliminated by heating the material to 470 K and leaving it at that temperature for $\geq$ 2 hours, restoring both conductivities to their initial, pre-illumination values. This process is called "annealing".

The magnitude of the defects states is represented by the fractional reduction of the dark conductivity:

$$|\sigma_B - \sigma_A|/\sigma_A$$

σ_B = dark conductivity after light exposure
σ_A = dark conductivity before any light exposure

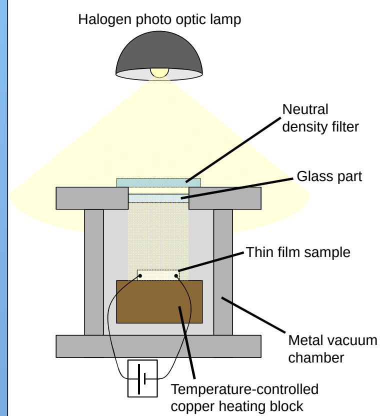
The number of incident photons per unit area, expressed as the total energy of such photons per unit area, is given by

$$\text{\# photons / area (in J/m}^2\text{)} = t\,\tau\,I_0$$

t = light transmission
τ = illumination time (seconds)
I_0 = original intensity of the light (W/m^2)

$|\sigma_B - \sigma_A|/\sigma_A$ depends on # photons / area.

Setup & Methods



Sample was mounted on a temperature-controlled copper heating block inside a metal vacuum chamber. During dark current measurements, the glass part was covered with a tinfoil sheet.

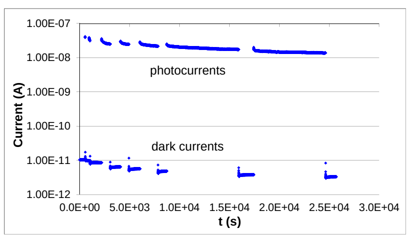
Used cumulative illumination method for each data acquisition: sample was alternately being left at dark and illuminated while measuring the current.

The acquisition was repeated for different transmitted light intensities by applying neutral density filters. Sample was annealed in between acquisitions.

The whole process was repeated for samples with different nc-Ge crystal fractions.

All photo- and dark currents were measured with 50 V applied across the sample at 320 K.

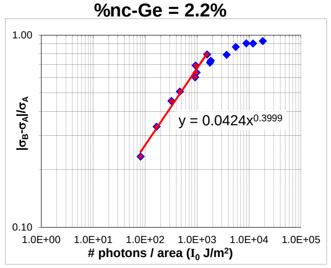
Results



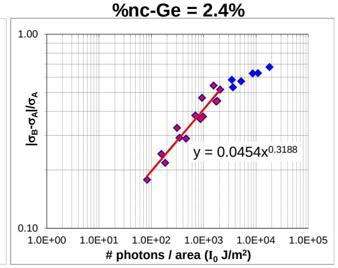
Complete current vs. time plot of the cumulative illumination method. For all data acquisitions, 7 different cumulative light exposure lengths were used:10 s, 100 s, 16 min, 0.5 hour, 1 hour, 3 hours, and 5 hours.

Reductions of both conductivities were observed, consistent to the SWE.

%nc-Ge = 2.2%



%nc-Ge = 2.4%



$|\sigma_B - \sigma_A|/\sigma_A$ vs. # photons / area for 2 samples with different nc-Ge crystal fractions. For each sample, the 4 different intensities were used: 100% (no filter), ~48%, ~19%, and ~9% transmission.

In both samples, $|\sigma_B - \sigma_A|/\sigma_A$ followed power law trend for lower # of photons / area up to ~$10^3\ I_0$ J/m^2 (I_0 = original intensity of the halogen lamp), then started to roll off, consistent with the constraint $\sigma_B > 0$.

The sample with 2.4% nc-Ge showed systematically smaller $|\sigma_B - \sigma_A|/\sigma_A$ than the 2.2% nc-Ge sample, which might suggest that the samples with higher nc-Ge crystal fraction have lower fractional reduction of the dark conductivity, and hence might be less prone to having light-induced structural defects.

Conclusion

We studied the dependence of the SWE on the number of incident photons in nc-Ge/a-Si:H thin film samples by varying the light exposure length and light intensity.

In both samples, $|\sigma_B - \sigma_A|/\sigma_A$ increased in power law fashion with exponents ~0.3-0.4 up to # photons / area ~$10^3\ I_0$ J/m^2, then started to roll off at higher number of photons, consistent with the constraint $\sigma_B > 0$.

The sample with higher nc-Ge crystal fraction had systematically lower fractional decreases of the dark conductivity than the sample with lower nc-Ge crystal fraction.

The latter result might suggest that the samples with higher nc-Ge crystal fractions may be more resistant to light-induced defects created by incident photons. Further studies involving more samples with broader range of nc-Ge crystal fractions are required to confirm this hypothesis.

Acknowledgements

Thanks to Zvie Razieli for his help and suggestions, and to the UROP for funding this project.

References

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